NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 3756

STUDY OF SIZE EFFECT IN SHEET-STRINGER PANELS

By J. P. Doman and Edward B. Schwartz

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SUMMARY

The object of this study was to determine whether there are significant size effects in compressive strength of large Z-stiffened sheet-stringer panels as compared with geometrically similar smaller models and thus to ascertain whether the prediction of the strength of large panels by model tests is reliable.

The specimens for the study were manufactured from 7075-T6 aluminum alloy. There were four representative types of panel designs, with full-scale and one-quarter-scale panels of each type.

A comparison of the average failing stresses shows that there is no significant effect due to the panel size.

For the panels tested, which failed by general instability, there was no significant compressive-strength size effect between the large Z-stiffened prototype and geometrically similar model panels.

INTRODUCTION

With the advent of large aircraft and high wing loadings, it has become necessary to test scale-model panels because of limitations of testing-machine sizes and loading capacities. Geometrically similar models of different sizes should, theoretically, all fail at the same stress; however, size effects of various sorts might influence the failing stress. The size effects may be present because of variation of material properties with sheet thickness, accuracy of construction, the impracticability of extending the geometrical similarity to the riveting, and various other factors.

The object of this project was to determine whether there are significant size effects in compressive strength of large Z-stiffened sheet-stringer panels as compared with geometrically similar smaller models and thus to ascertain whether the prediction of the strength of large panels by model tests is reliable.

This work was conducted at the Aeronautical Structures Laboratory of the Naval Air Material Center and has been made available to the National Advisory Committee for Aeronautics for publication because of its general interest.

DESCRIPTION

The test specimens for this study were manufactured by standard procedures using standard sheet material of 7075-T6 aluminum alloy and available aluminum-alloy rivets. The stiffeners were extruded from special dies in order to have Z-stiffeners of desired proportions and to obtain geometric similarity, but standard Aluminum Company of America extrusion tolerances, outlined in reference 1, were used.

The panels were designed in accordance with the method of designing for maximum structural efficiency, as outlined in reference 2. The basic parameters and their representative values used in the four types of panel designs are presented in table I. Reference 2, which deals with 2024-T, was used because, at the time of designing the panels, no design charts for 7075-T6 panels were available. Without actual test work there was no way of accurately obtaining analogous sets of curves for 7075-T6. Therefore, for lack of a better method, it was assumed that the nondimensional, optimum-panel-proportion curves for 2024-T would hold with sufficient accuracy for 7075-T6. The diameter and pitch for the rivets of the panels were chosen in accordance with references 3 and 4 in order to obtain optimum strength and practical spacings.

Three panels of each of the four types were manufactured. Geometrically similar panels, one-quarter scale of the designed panels, were also manufactured, using standard procedures and standard sheet thicknesses. Comparing the panel designs for this study against the subsequently published design charts for 7075-T6 in reference 5, the charts show that the panel proportions were not far from the minimum weight proportions and that the panels were to fail as columns without previous sheet buckling.

The ends of all panels were machined to give good contact surfaces. Each panel was installed in the testing machine and loaded to 3 percent of the predicted failing load. The contact surfaces were visually checked and remachined, if necessary, to give a good contact with the testing-machine platens.

The final machined dimensions of the full- and one-quarter-scale panels are presented in table II. The symbols for the dimensions are defined in figure 1 and in appendix A.

All panels had SR-4 electrical resistance-wire strain gages installed back to back across the center of the panel on the sheet in the middle of each bay. The full-scale panels had additional back-to-back gages installed across the center of the panel on the outstanding flanges of the Z-sections.

METHOD

The panels were tested in compression to failure in the 5,000,000-pound-capacity, universal, hydraulic, testing machine. Figure 2 shows a full-scale panel being installed in the testing machine. The panels were centered in the testing machine, held straight and in position by the testing-machine alining bars, and loaded to 3 percent of the estimated failing load. The alining bars were withdrawn from the panel in order to check the contact surfaces between the machine platens and the specimens. Strain readings were taken at convenient increments of load in order to determine whether the panels were loaded evenly between the sheet and stiffeners and across the panel width. The two tapered "leveling disks" of the testing machine were moved as necessary in order to tilt the loading surface of the testing machine to obtain even load distributions. Less than 10-percent variation in strain readings at 15 percent of the estimated failing load was considered even load distribution. The strain gages were read during tests in order to detect, by the strain-reversal method, the presence of buckling. The loads indicated were accurate to within ±1/2 percent of the true load applied.

Compression coupons were made and tested from each component of all panels in order to find a 0.2-percent-offset compressive yield stress for the panel materials.

RESULTS

The failing loads and calculated stresses (P/A) for the panels are presented in table III. In order to obtain data comparable on the basis of the same material strength, the mean stresses for the one-quarter-scale panels were corrected for difference in material strength between the full- and one-quarter-scale panels according to the nondimensional material correction chart for 7075-T6 clad sheet in reference 6. Both corrected and uncorrected stresses are included in table III.

Figures 3 to 14 show the failed specimens in order of type. First, two views of each large panel type are shown and then one view of each small type is shown. All panels failed suddenly, as columns, and no interrivet or sheet buckling occurred.

The average compressive yield strengths (0.2-percent offset) of the 7075-T6 material were:

Full-scale sheets, psi	77,160
Full-scale stiffeners, psi	80,200
1/4-scale sheets, psi	70,555
1/4-scale stiffeners, psi	74,630

Because two of the failing stresses for the full-scale type D panels are very nearly equal while the third is considerably larger, there is a tendency to reject this large value as being an "outlying observation." Although this could not be justified on the basis of these three stresses alone, it can be shown after an estimate of the experimental error based on 21 other failing stresses that the difference between the largest type D panel observation, 58,650 psi, and the other D panel observations is statistically significant at the 0.5-percent level. (See appendix B.) This means that if the largest observation is rejected the probability is only 1/200 that a wrong decision was made. In view of this, the high stress for the one type D panel can be rejected.

It can be seen, by comparing the average failing stresses in table III, that the greatest variation between full- and one-quarter-scale panels is only 2.8 percent. Comparing the full-scale-panel stresses with the corrected one-quarter-scale stresses shows a reduction of variation to 2.4 percent.

The only size-effect factor observed during the study was the type of failure. At failure of the one-quarter-scale panels, the web and outstanding leg of a few of the Z-section stiffeners jumped off the panels. At failure of full-scale panels, nearly all the Z-section stiffeners either jumped off or shattered. This effect can be observed by comparing the figures showing the failed specimens.

CONCLUDING REMARKS

There was no significant size effect in the compressive strength of the large-scale Z-stiffened panels tested as compared with geometrically similar small-scale panels. Therefore, the compressive strength of large-scale panels failing by general instability may be predicted from model tests or accepted design data presented as nondimensional parameters.

Aeronautical Structures Laboratory,
Naval Air Material Center,
Philadelphia, Pa., June 13, 1955.

APPENDIX A

SYMBOLS

A	cross-sectional area
b_A	width of attached flange, in.
b_F	width of outstanding flange, in.
b_S	spacing of stiffeners on sheet, in.
b_W	width of stiffener web, in.
c	coefficient of end fixity
d	rivet diameter, in.
L	length of panel, in.
P	load, kips
P_i	load per inch of panel width, kips/in.
p	rivet pitch, in.
$r = t_W$	
s	rivet spacing, in.
t_S	thickness of sheet, in.
t_W	thickness of stiffener web, in.
W	width of specimens, in.

APPENDIX B

STATISTICAL ANALYSIS

By Edward B. Schwartz

Formula 12.7.4 on page 333, of "Statistical Theory With Engineering Applications" by Hald (ref. 7) may be written

$$\frac{X_{(n)P} - \bar{X}}{S_f} \approx \mu_{P_1}\left(1 + \frac{3}{f}\right)\sqrt{\frac{n - 1}{n}}$$

where

$$P_1 = 1 - \frac{1 - P}{n}$$

n number of observations in sample (3 herein)

$X_{(n)P}$ P-fractile of cumulative distribution of $X_{(n)}$

$X_{(n)}$ largest observation in a sample of n

$\bar{X}$ sample mean

S_f estimate of population variance computed from a second independent sample from same population (herein, the remaining 21 observations)

f number of degrees of freedom of this estimate (herein, $7 \times 2 = 14$)

μ normally distributed variable with zero mean and unit variance

μ_{P_1} P_1-fractile of μ

The sample of n is assumed to be drawn from a normally distributed population.

Each group of three stresses furnishes an estimate, with two degrees of freedom, of the population variance. On the assumption that all 7 such values are estimates of the same population variance, they can be pooled to give a single estimate of 14 degrees of freedom. Doing this gives

$$S_f = 1,650 \text{ lb}$$

Values of μ_{p_1} can be obtained from standard statistical tables.

Application of the above formula now shows that

$$X_{(n)} = 58,650 > X_{(n)99.5 \text{ percent}}$$

Therefore, the value 58,650 psi can be rejected as an "outlying observation" with 99.5-percent certainty.

REFERENCES

1. Anon.: Alcoa Structural Handbook. Aluminum Co. of Am. (Pittsburgh), 1950.

2. Schuette, Evan H.: Charts for the Minimum-Weight Design of 24S-T Aluminum-Alloy Flat Compression Panels With Longitudinal Z-Section Stiffeners. NACA WR L-197, 1945. (Supersedes NACA ARR L5F15.)

3. Dow, Norris F., and Hickman, William A.: Effect of Variations in Diameter and Pitch of Rivets on Compressive Strength of Panels With Z-Section Stiffeners - Panels of Various Lengths With Close Stiffener Spacing. NACA TN 1421, 1947.

4. Dow, Norris F., and Hickman, William A.: Effect of Variation in Diameter and Pitch of Rivets on Compressive Strength of Panels With Z-Section Stiffeners. I - Panels With Close Stiffener Spacing That Fail by Local Buckling. NACA WR L-44, 1945. (Supersedes NACA RB L5G03.)

5. Hickman, William A., and Dow, Norris F.: Direct-Reading Design Charts for 75S-T6 Aluminum-Alloy Flat Compression Panels Having Longitudinal Extruded Z-Section Stiffeners. NACA TN 2435, 1952.

6. Anon.: Strength of Metal Aircraft Elements. ANC-5, Munitions Board Aircraft Committee, Revised ed., June 1951.

7. Hald, A.: Statistical Theory With Engineering Applications. John Wiley & Sons, Inc., 1952.

TABLE I

PANEL DESIGN PARAMETERS

Panel type	Structural loading parameter, $P_i/L/\sqrt{c}$ (a)	t_W/t_S (a)	t_W, in. (a)	t_S, in. (a)	b_F (a)	b_A (a)
A	0.4	0.5	0.25	0.5	$0.5b_W$	$9t_W$
B	.4	1.0	.25	.25	$.5b_W$	$9t_W$
C	.8	.5	.25	.5	$.5b_W$	$9t_W$
D	.8	1.0	.25	.25	$.5b_W$	$9t_W$

[a] P_i load per inch of panel width, in.

L length of panel, in.

c coefficient of end fixity

t_W thickness of stiffener web, in.

t_S thickness of sheet, in.

b_F width of outstanding flange, in.

b_W width of stiffener web, in.

b_A width of attached flange, in.

TABLE II

PANEL DIMENSIONS

Panel			Sheet			Z-stiffener					Rivets		
Type	Scale	Number	L, in.	W, in.	t_S, in.	Number	b_F, in.	b_A, in.	b_W, in.	t_W, in.	d, in.	p, in.	s, in.
A	Full	1	$161\frac{7}{8}$	$62\frac{3}{8}$									
		2	$161\frac{7}{8}$	$62\frac{3}{8}$	1/2	6	$2\frac{7}{8}$	$2\frac{1}{4}$	$6\frac{1}{32}$	1/4	3/4	$2\frac{1}{4}$	12
		3	$161\frac{3}{8}$	$62\frac{3}{8}$									
	1/4	1	$40\frac{15}{32}$	$15\frac{9}{16}$									
		2	$40\frac{1}{2}$	$15\frac{9}{16}$	1/8	6	11/16	9/16	$1\frac{15}{32}$	1/16	3/16	9/16	3
		3	$40\frac{1}{2}$	$15\frac{9}{16}$									
B	Full	1	$172\frac{3}{8}$	$48\frac{25}{32}$									
		2	171	$48\frac{3}{4}$	1/4	8	$2\frac{7}{8}$	$2\frac{1}{4}$	$6\frac{1}{32}$	1/4	1/2	$1\frac{1}{2}$	$6\frac{5}{8}$
		3	$172\frac{3}{8}$	$48\frac{13}{16}$									
	1/4	1	$44\frac{1}{4}$	$12\frac{1}{2}$									
		2	$44\frac{1}{4}$	$12\frac{1}{2}$	1/16	8	11/16	9/16	$1\frac{15}{32}$	1/16	1/8	3/8	$1\frac{11}{16}$
		3	$44\frac{5}{16}$	$12\frac{1}{2}$									
C	Full	1	$107\frac{15}{16}$	$54\frac{7}{8}$									
		2	$107\frac{7}{8}$	$54\frac{7}{8}$	1/2	8	$2\frac{1}{2}$	$2\frac{1}{4}$	$5\frac{1}{32}$	1/4	3/4	$2\frac{1}{4}$	$7\frac{1}{2}$
		3	106	$54\frac{7}{8}$									
	1/4	1	27	$13\frac{3}{4}$									
		2	27	$13\frac{3}{4}$	1/8	8	5/8	9/16	$1\frac{1}{4}$	1/16	3/16	9/16	$1\frac{7}{8}$
		3	27	$13\frac{3}{4}$									
D	Full	1	$128\frac{3}{4}$	$40\frac{5}{8}$									
		2	$128\frac{7}{8}$	$40\frac{9}{16}$	1/4	10	$2\frac{1}{2}$	$2\frac{1}{4}$	$5\frac{1}{32}$	1/4	1/2	$1\frac{1}{2}$	$4\frac{1}{4}$
		3	$128\frac{7}{8}$	$40\frac{5}{8}$									
	1/4	1	33	11									
		2	33	$10\frac{3}{8}$	1/16	10	5/8	9/16	$1\frac{1}{4}$	1/16	1/8	3/8	$1\frac{3}{32}$
		3	33	11									

TABLE III

FAILING LOADS AND CALCULATED STRESSES

Panel type	Load, lb		Stress, P/A, psi		Mean stress, psi		Corrected stress, 1/4 scale
	Full scale	1/4 scale	Full scale	1/4 scale	Full scale	1/4 scale	
	2,290,000	135,000	47,780	45,380			
A	2,350,000	150,400	49,010	50,550	48,460	47,393	48,340
	2,330,000	137,600	48,590	46,250			
	1,532,000	95,400	44,490	44,290			
B	1,516,000	91,200	44,030	42,340	44,960	44,083	44,303
	1,600,000	97,000	46,360	45,620			
	2,850,000	173,000	60,280	58,620			
C	2,750,000	170,000	58,170	57,610	59,930	59,077	60,554
	2,900,000	180,000	61,340	61,000			
	1,790,000	109,000	51,210	48,920			
D	1,800,000	110,000	51,520	50,270	[a]51,365	49,910	50,159
	2,050,000	112,600	58,650	50,540			

[a]Highest failing panel stress rejected (see appendix B).

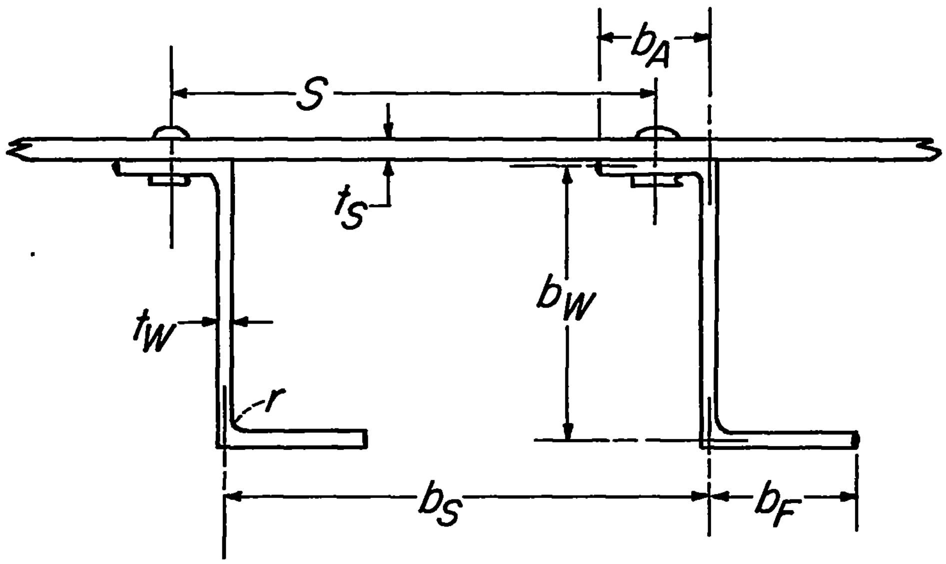
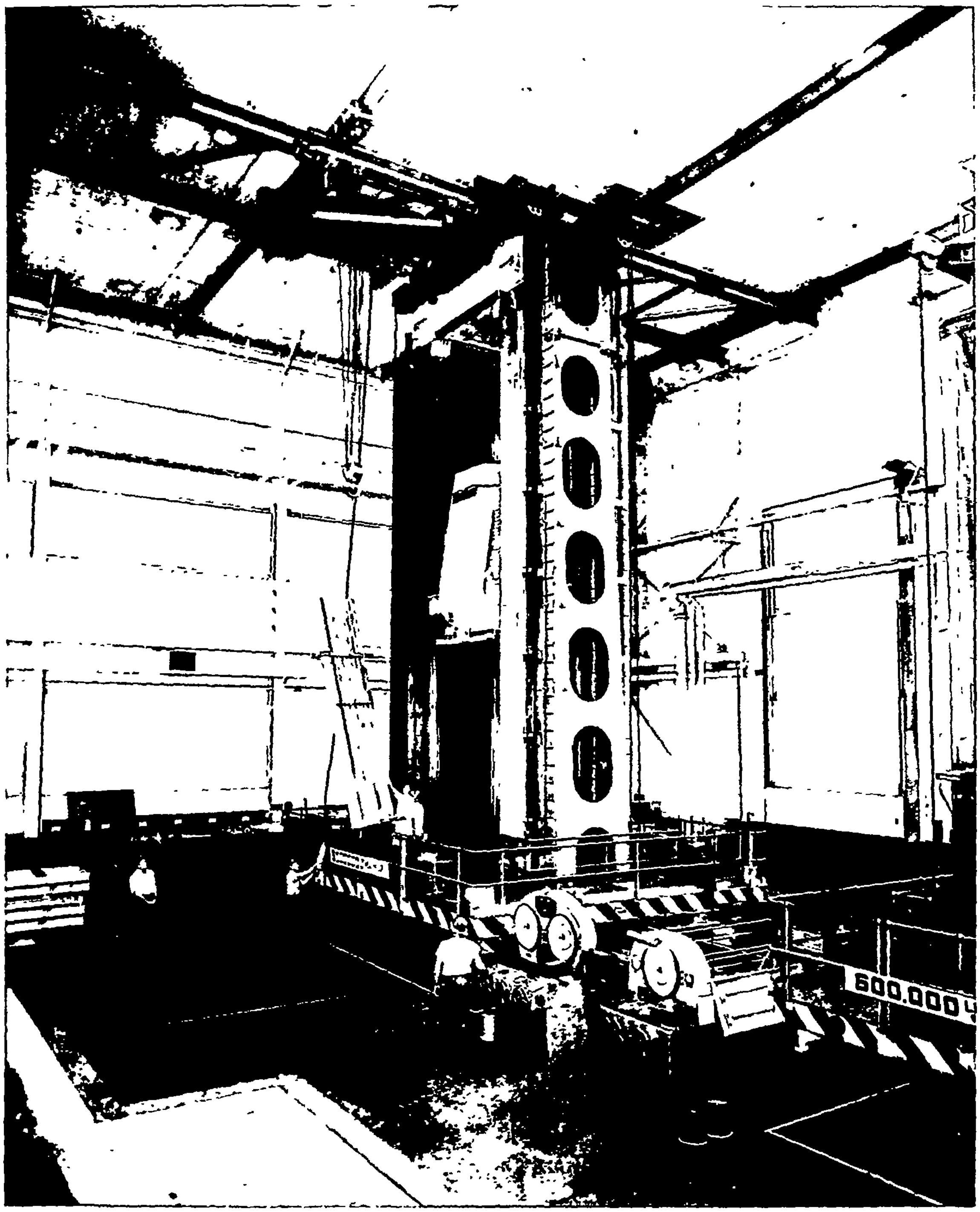


Figure 1.- Symbols for panel dimensions (see table II and appendix A).

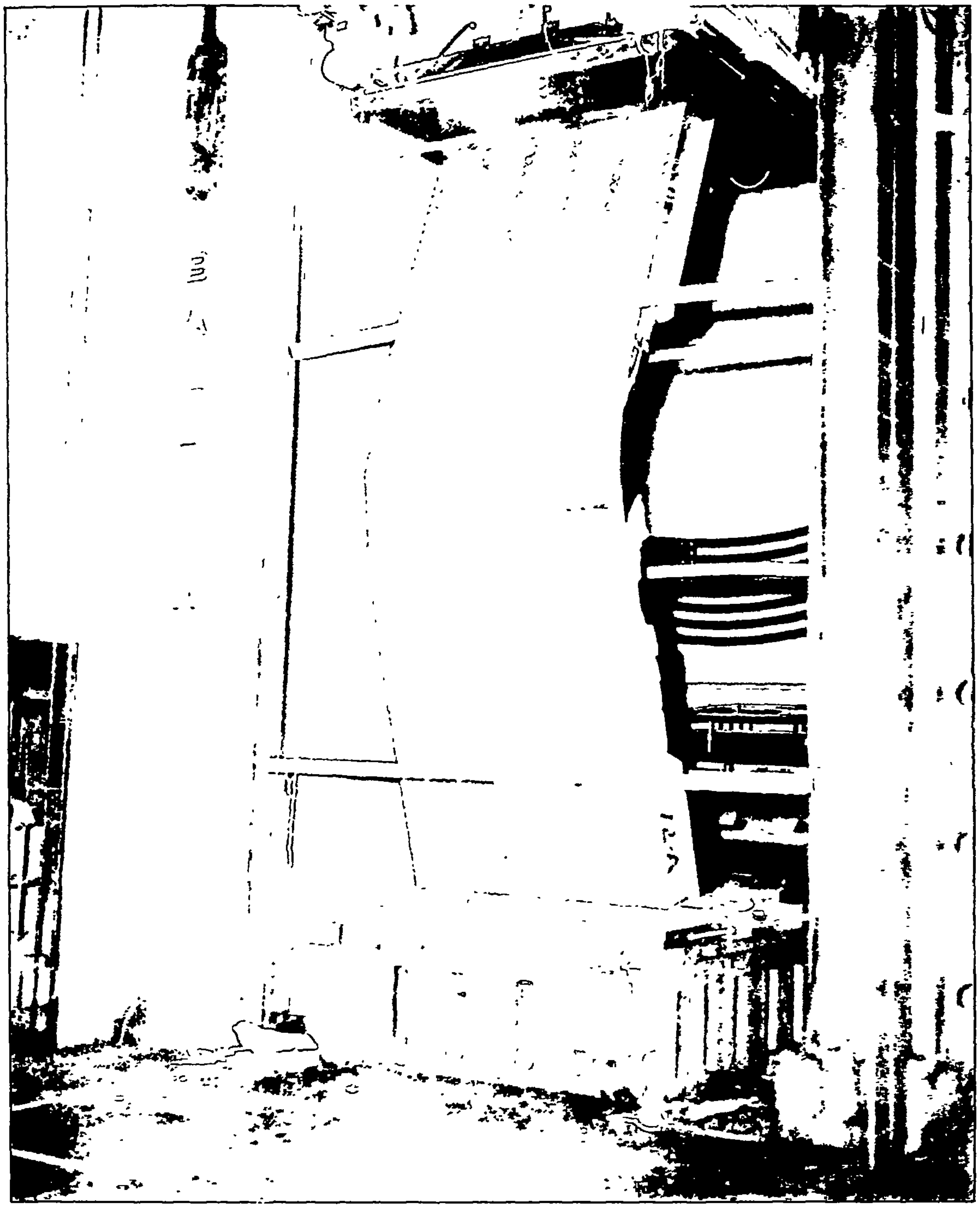


L-93499

Figure 2.- Installing full-scale panel in 5,000,000-pound-capacity testing machine.

L-93500

Figure 3.- Stiffener side of failed full-scale type A panel.

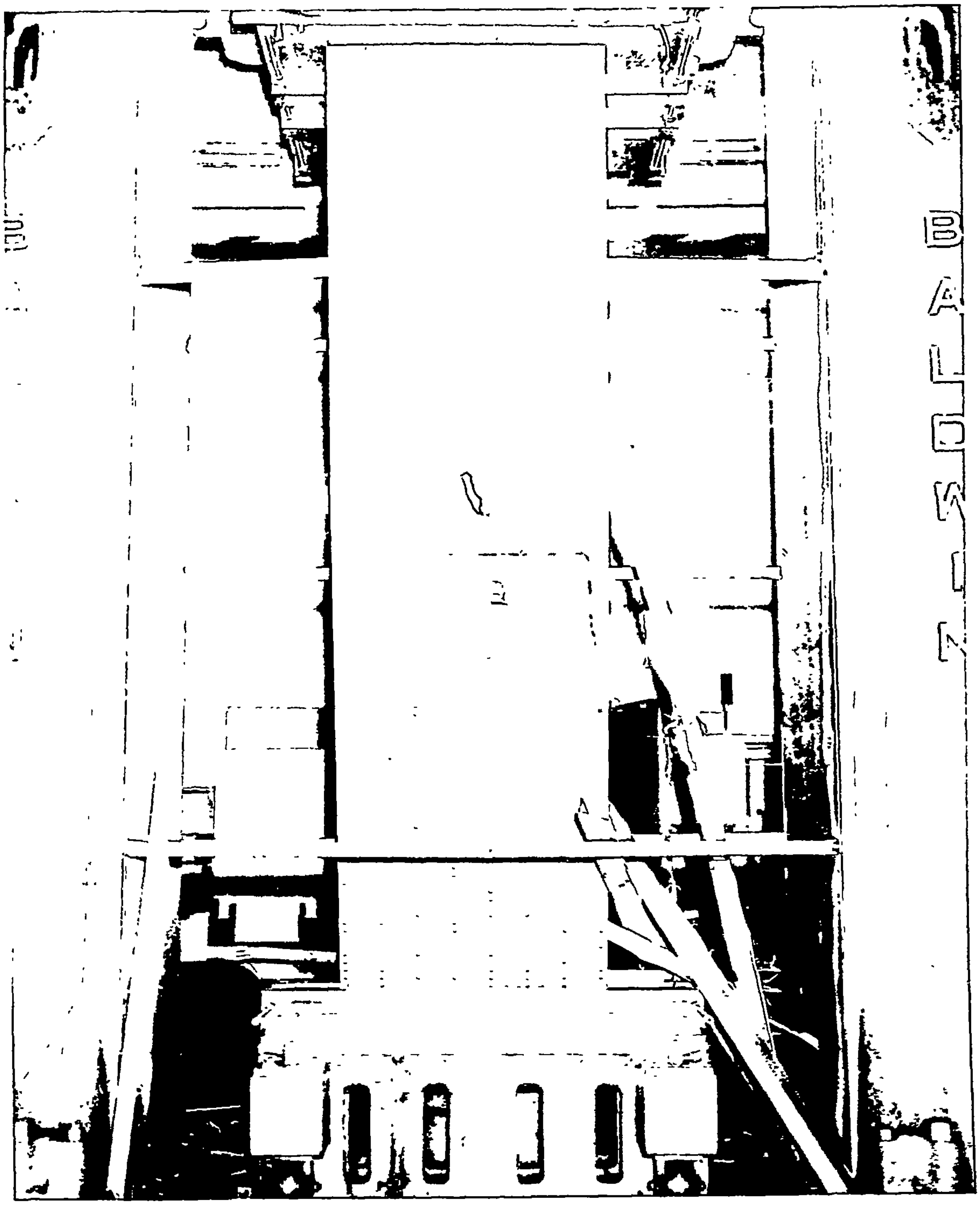


L-93501

Figure 4.- Sheet side of failed full-scale type A panel.

L-93502

Figure 5.- Stiffener side of failed full-scale type B panel.



L-93503

Figure 6.- Sheet side of failed full-scale type B panel.

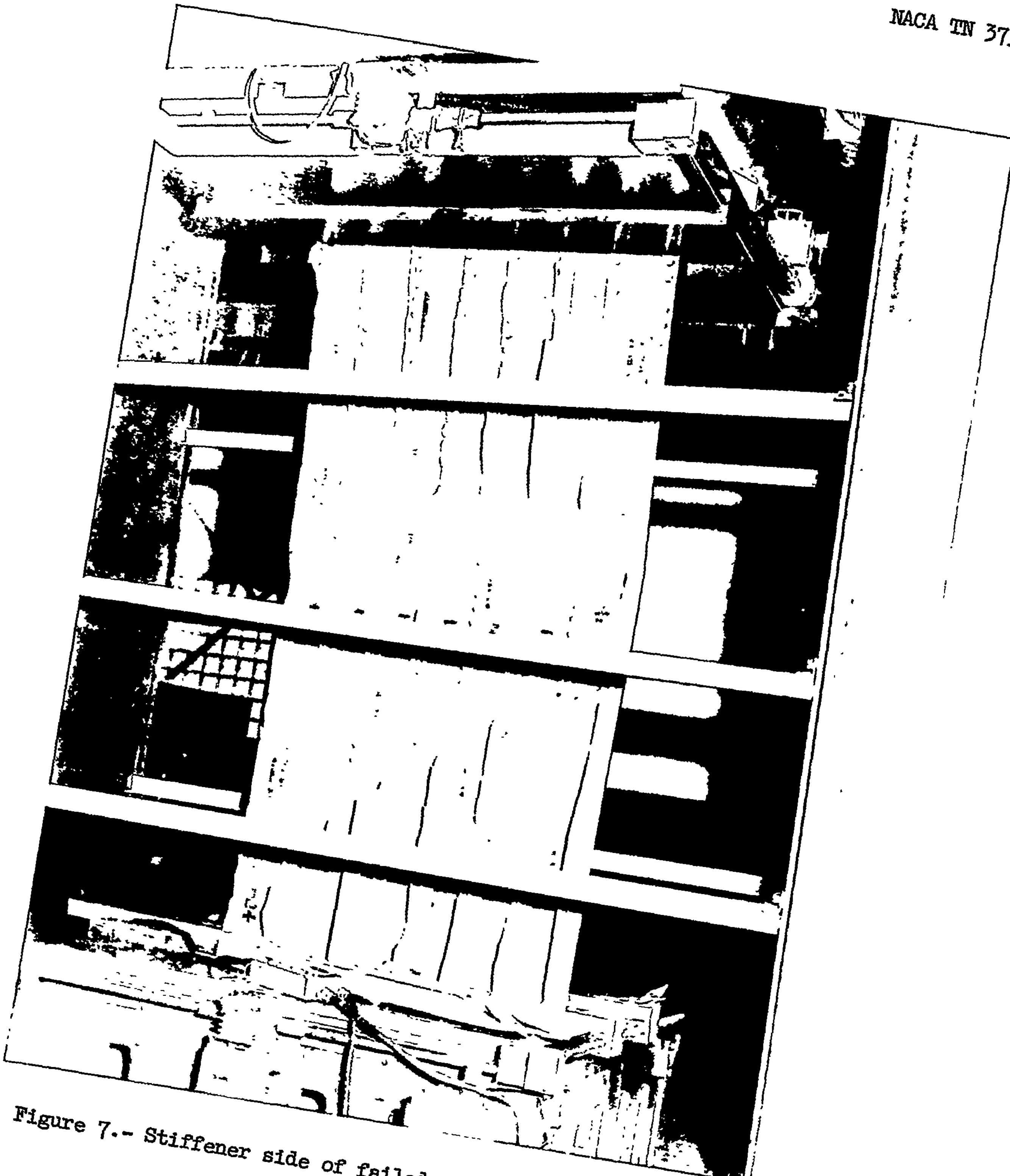
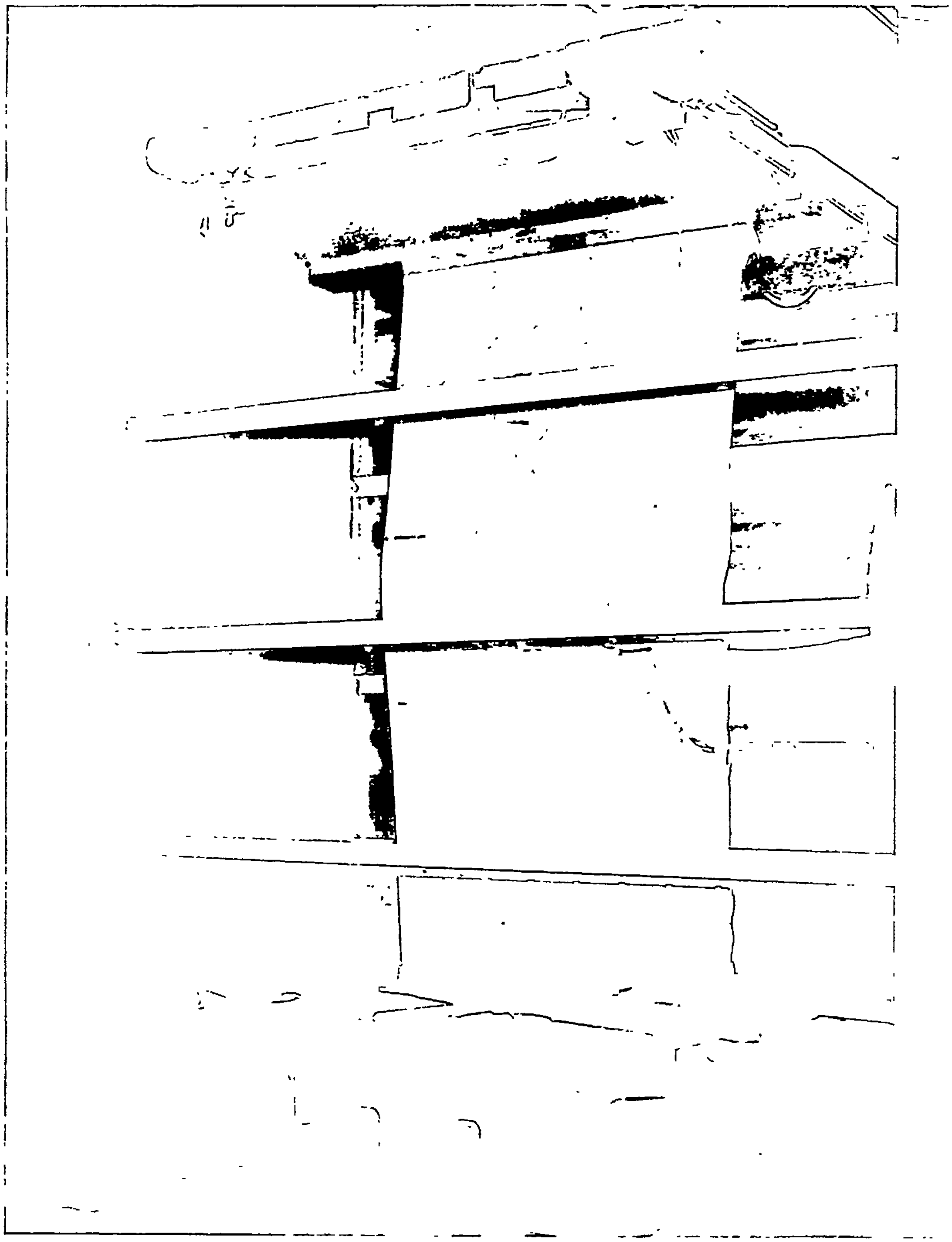
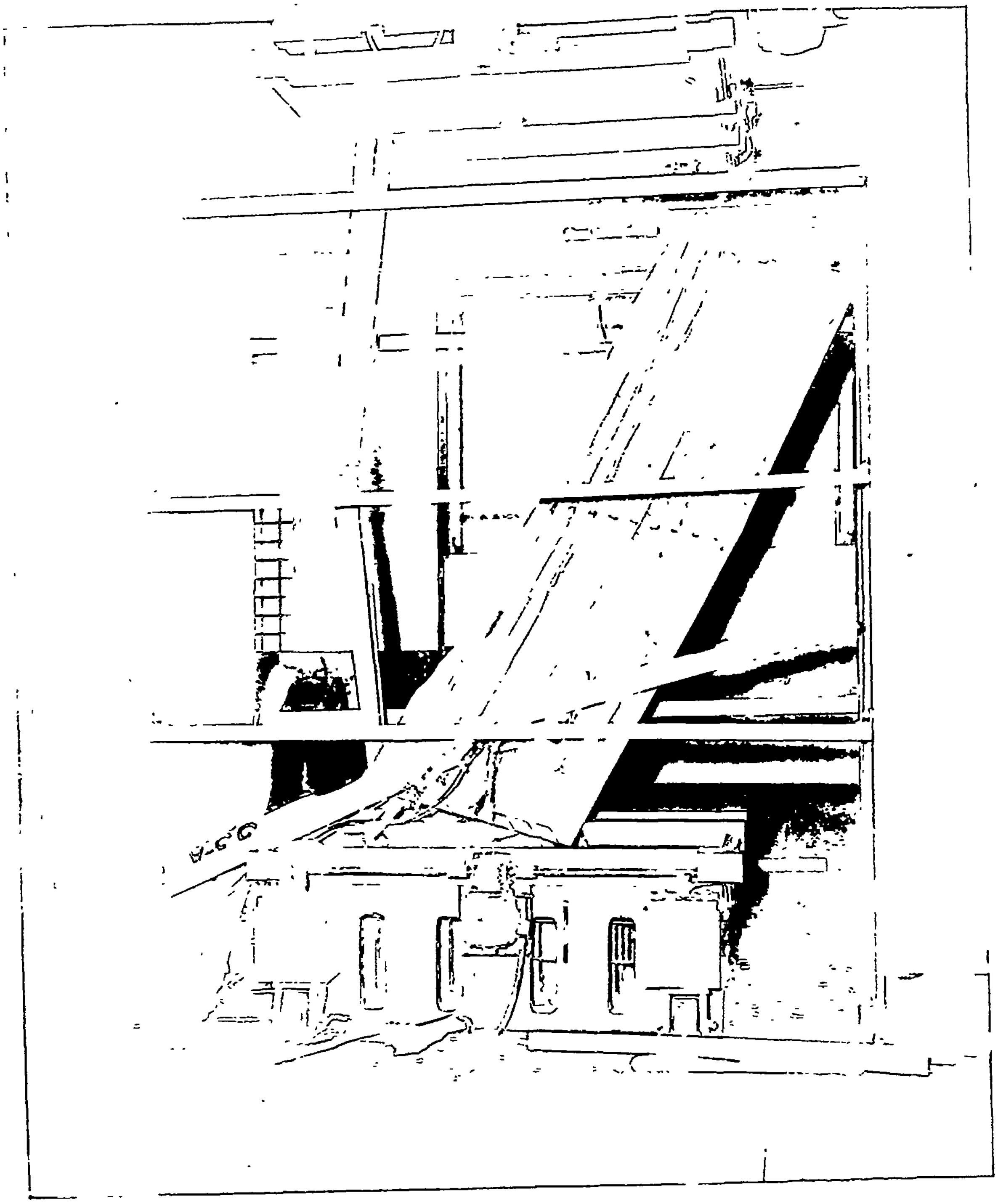


Figure 7.- Stiffener side of failed full-scale type C panel. L-93504



L-93505

Figure 8.- Sheet side of failed full-scale type C panel.



L-93506

Figure 9.- Stiffener side of failed full-scale type D panel.

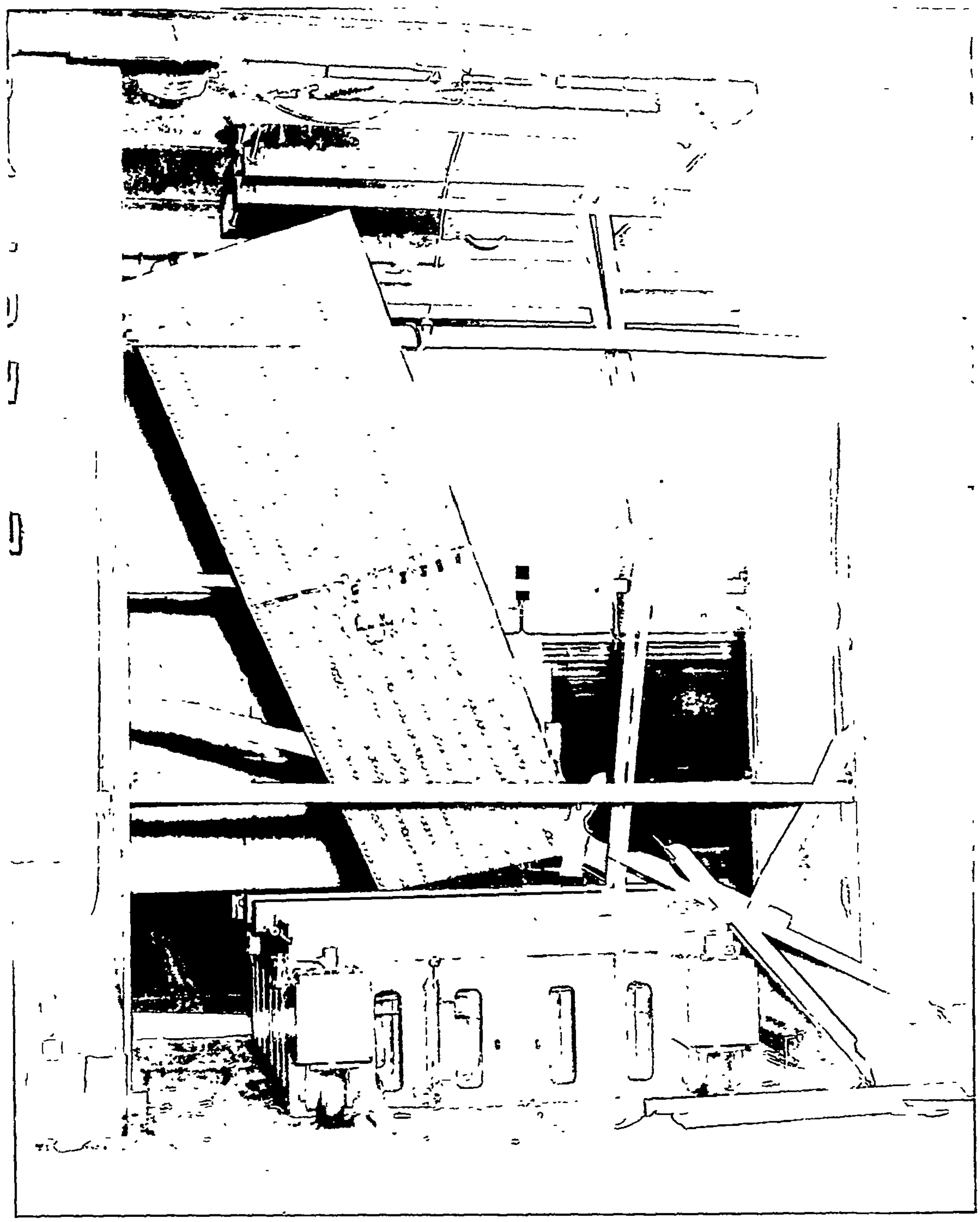
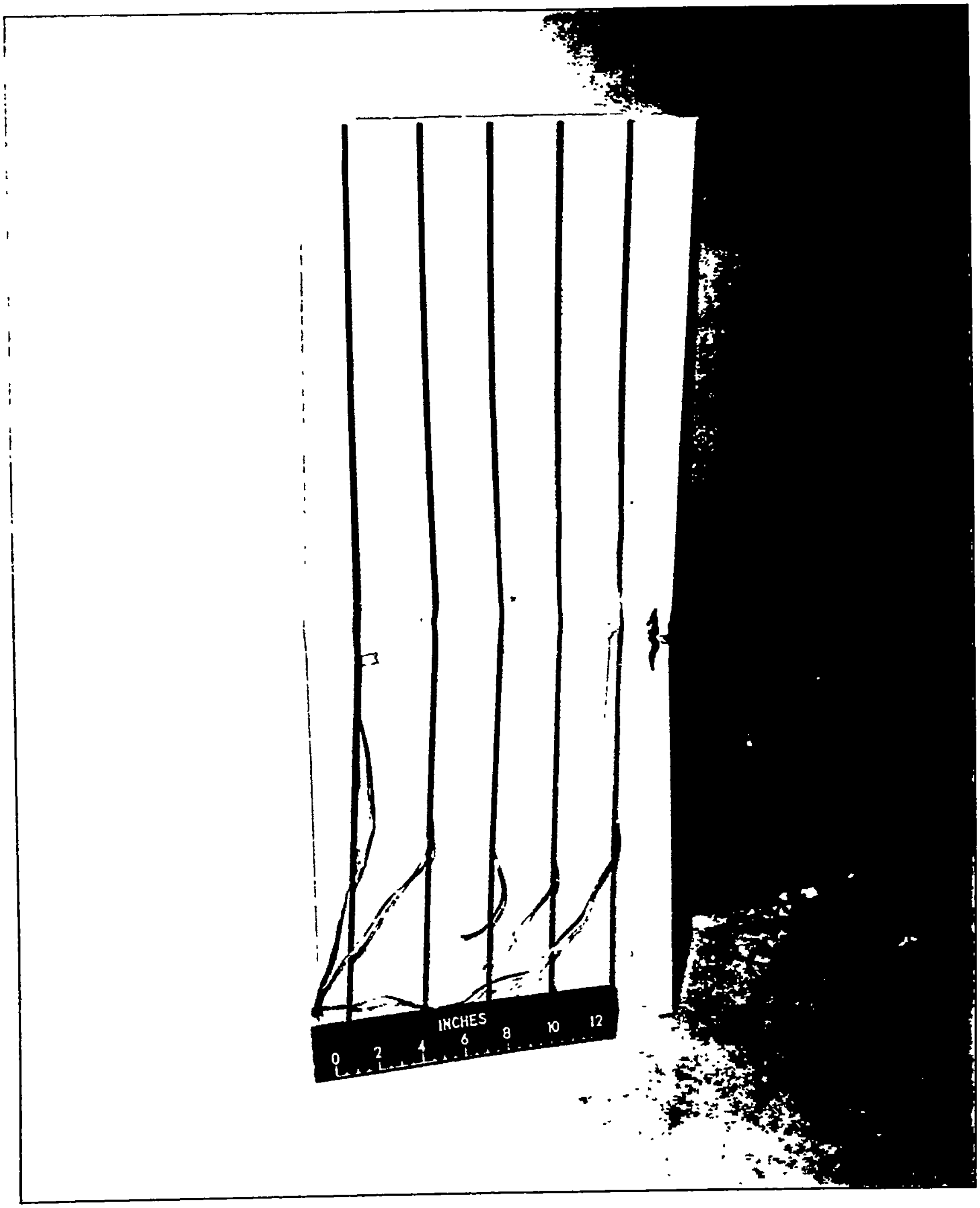
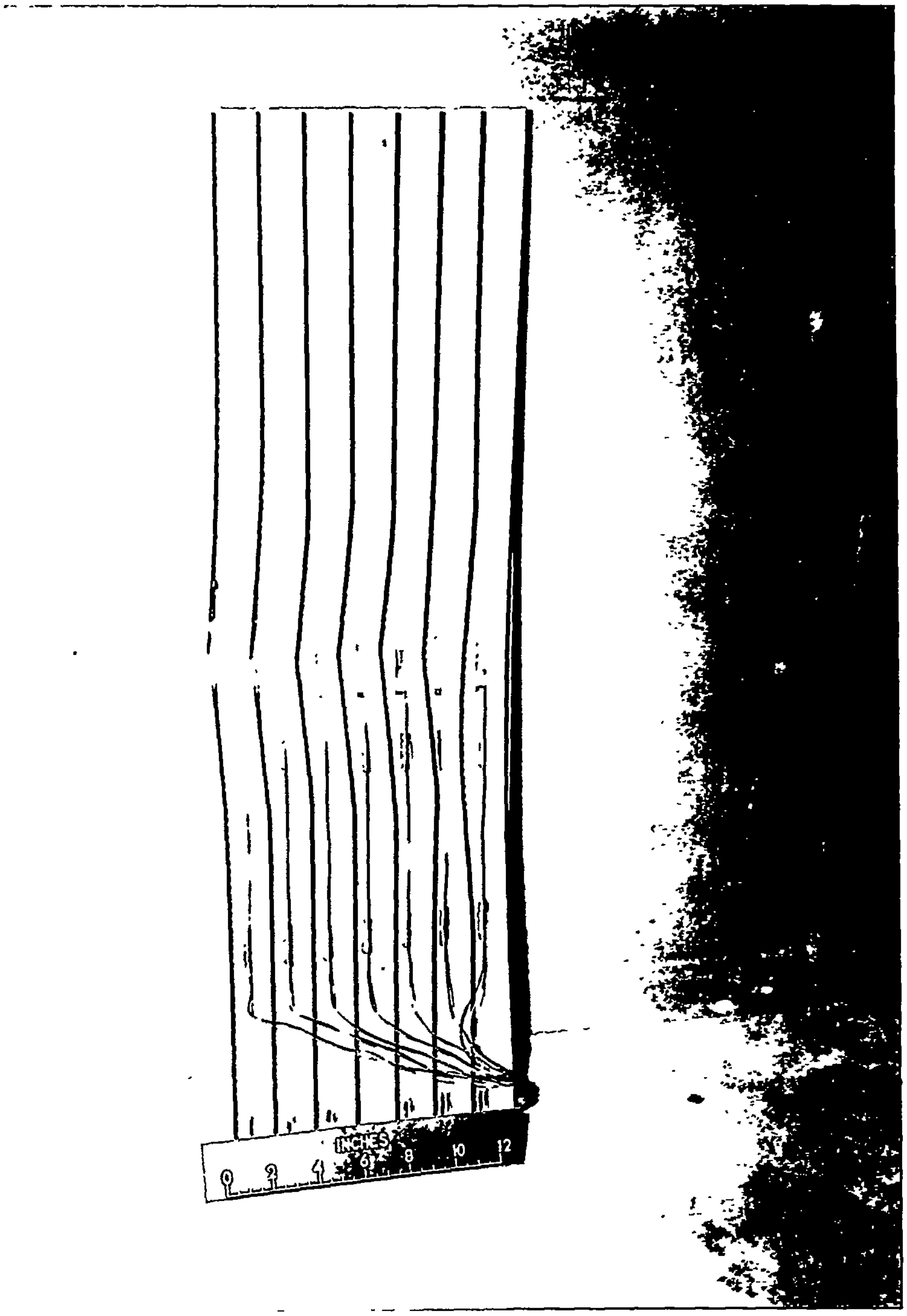


Figure 10.- Sheet side of failed full-scale type D panel. L-93507



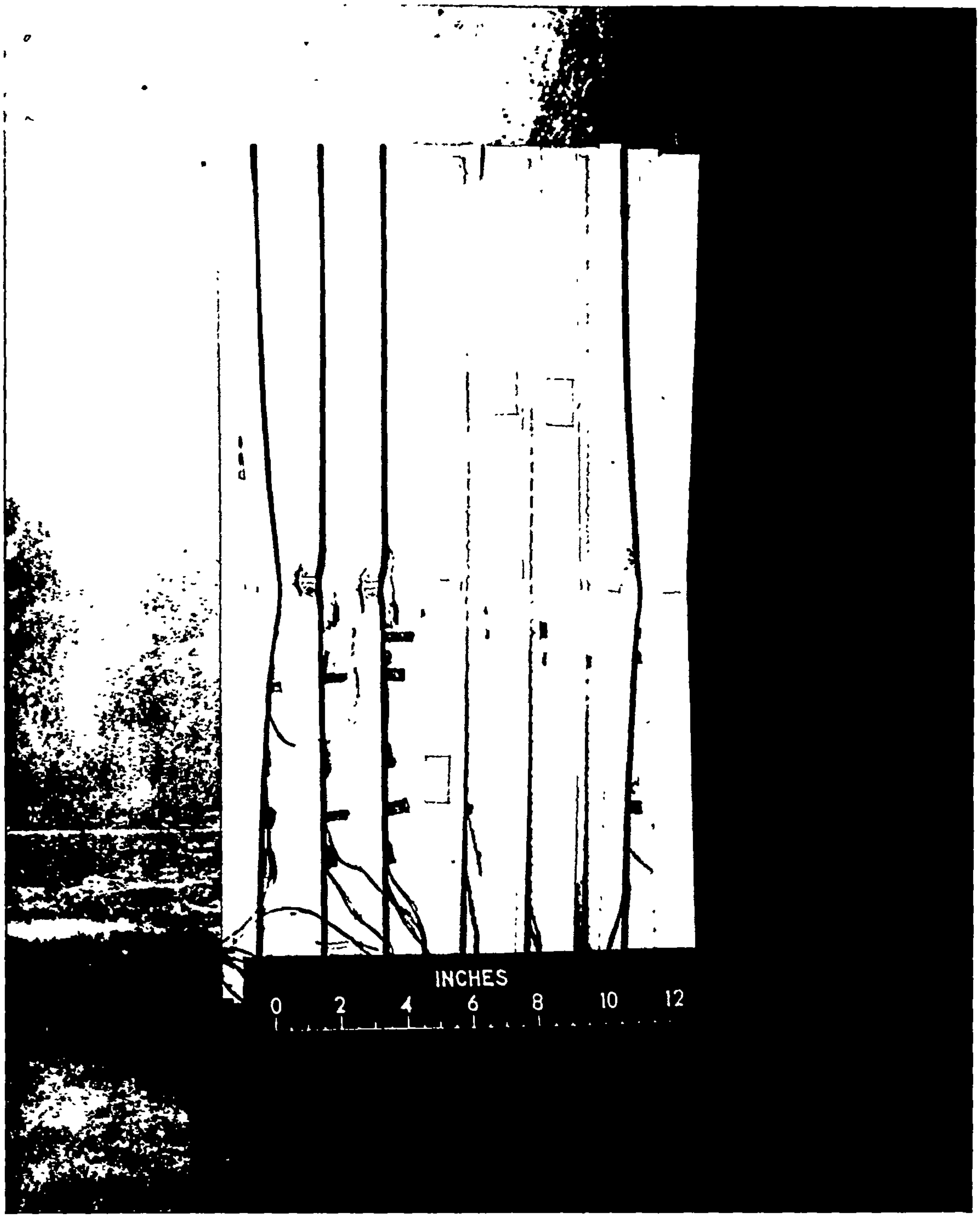
L-93508

Figure 11.- Failed one-quarter-scale type A panel.



L-93509

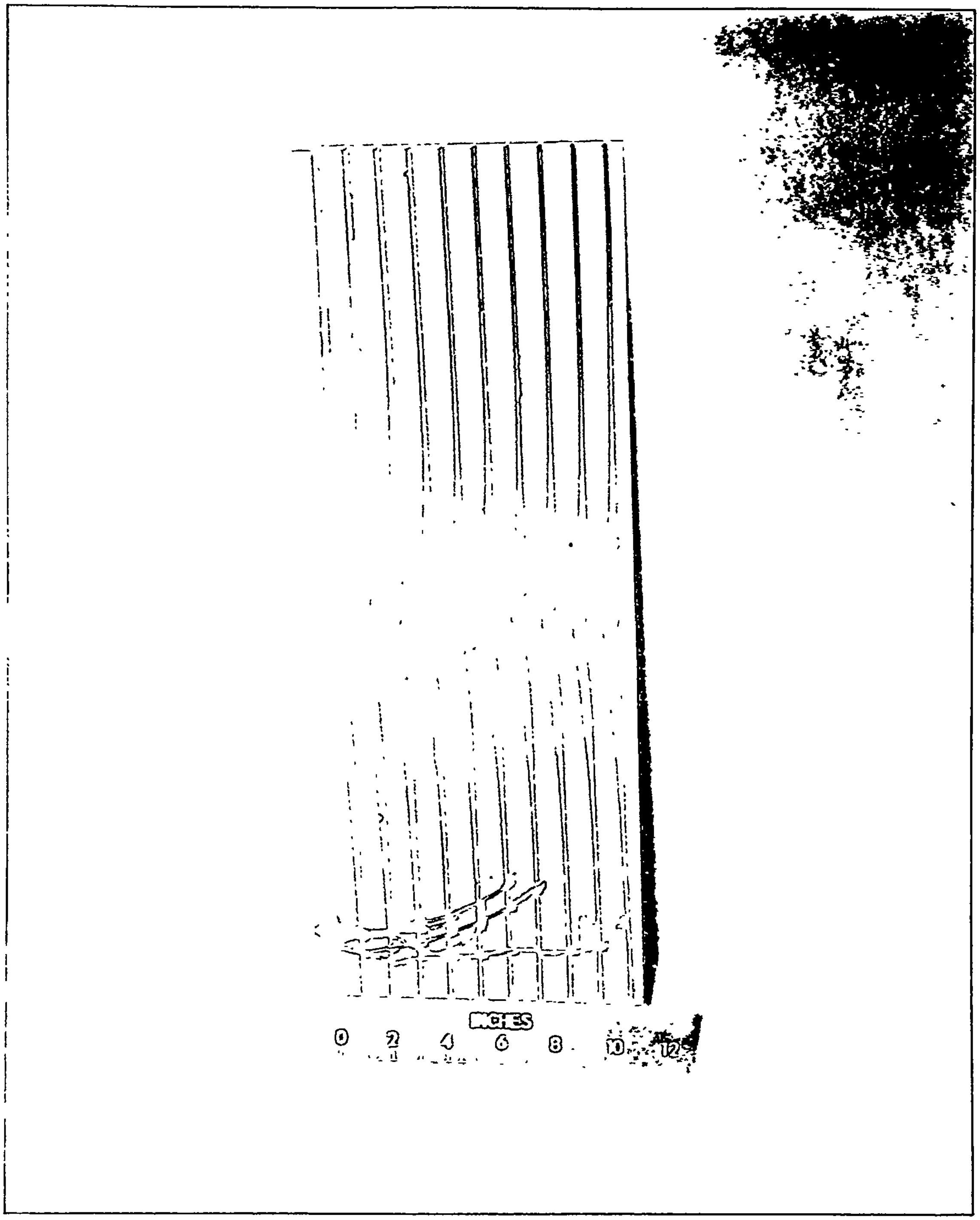
Figure 12.- Failed one-quarter-scale type B panel.



L-93510

Figure 13.- Failed one-quarter-scale type C panel.

R



L-93511

Figure 14.- Failed one-quarter-scale type D panel.